

# Fire Suppression Using Solid Propellant Gas Generator Technology

Gary F. Holland, Lyle D. Galbraith

Olin Aerospace Company

Solid propellant gas generator (SPGG) technology has recently evolved to become an effective, environmentally benign alternative to Halon 1301 in fire suppression applications. In one aspect of the SPGG approach, a solid propellant mixture of fuel + oxidizer is combusted to produce large volumes of a mixture of inert gases (nitrogen, carbon dioxide and water vapor –  $N_2$ ,  $CO_2$  and  $H_2O$ ). This mixture of gases creates an oxygen-deficient environment which no longer supports combustion and rapidly suppresses various fire scenarios. The primary mechanism of effectiveness for this SPGG approach appears to be a combination of flame detachment that arises from the rapid generation of large volumes of gas, plus creation of an environment which is too depleted in oxygen to support hydrocarbon combustion. This rapidly evolving field has been the topic of a recent NIST workshop(1).

Some of the earliest solid propellant/fire suppression-type technology was discussed by Filter et al in 1976(2). Later, Reed et al. described a family of propellant formulations which combusted flamelessly to yield large amounts of nitrogen gas(3). More recently, several other solid propellant formulations have been described in the patent and technical literature(4, 5). The concepts described by Galbraith et al. include stoichiometrically-balanced formulations which yield large amounts of nitrogen gas together with  $CO_2$  and water vapor(4). Suitable concentrations of the exhaust can be directed into a fire zone to effect fire suppression.

Flow rates and chemical reaction times can be addressed for solid propellants by controlling the propellant combustion process. Two important considerations in optimizing a system for fire suppression are the rate of agent delivery and the total time over which the agent is delivered. The rate of combustion for a given propellant is a function of pressure and is described by

$$\text{rate} = A * P^n$$

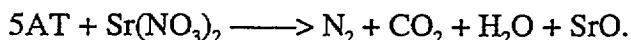
where the exponent  $n$  is characteristic of the propellant's pressure sensitivity. The rate of mass generation during propellant combustion,  $dm_{\text{gen}}/dt$ , is given by

$$dm_{\text{gen}}/dt = \rho_p * A_b * r,$$

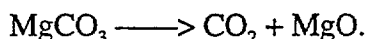
where  $\rho_p$  = propellant density,  $A_b$  = burning surface area and  $r$  = rate of combustion. Larger propellant loads, with their larger mass and larger surface area, require a longer time for complete combustion. Therefore, the rate of agent generation and the total delivery time are controlled via the combustion pressure and the burning surface area.

Solid propellants provide a means for circumventing the high-pressure bottle penalty of stored gases with efficient high-density storage of  $N_2$ ,  $CO_2$  and  $H_2O$  in vessels at ambient pressures. One suitable solid propellant formulation is based upon sodium azide,  $NaN_3$ . Mixtures of  $NaN_3$  with iron oxide,  $Fe_2O_3$ , upon combustion yield nearly pure nitrogen gas. Since  $N_2$  is an effective physically-acting fire suppressant, typical critical concentrations are readily obtained by extrapolation from, e.g. cup burner studies. One challenge in using azide-based SPGG's is the toxicity associated with azide materials.

Another suitable solid propellant formulation avoids the toxicological shortcomings of azides, relying instead on the combustion of an energetic fuel (e.g. 5-amino-tetrazole) with an inorganic oxidizer (e.g. strontium nitrate):



Since the rate of agent generation is important, the rate of propellant combustion can be moderated with combustion modifiers such as magnesium carbonate,  $\text{MgCO}_3$ , which absorbs heat and decomposes to form  $\text{CO}_2$ :



Through careful control of the propellant combustion rate, the solid residue (e.g.  $\text{SrO}$ ,  $\text{MgO}$ ) from propellant combustion can be restricted to the combustion reactor rather than exhausting into the protection volume.

The SPGG technologies described above can be competitive with Halon systems, particularly if their distribution in the volume-of choice is well understood. To this end, we have obtained temporally- and spatially-resolved analysis of  $\text{CO}_2$  and  $\text{O}_2$  concentration levels over the course of a fire suppression test event.  $\text{CO}_2$  sensing is accomplished using optical detection of its IR absorption. Oxygen detection utilizes a zirconia electrochemical sensor similar to those used in automobile combustion manifolds. Measurements in highly turbulent conditions correlate well with cup burner measurements and indicate that when oxygen concentrations are reduced by approximately 25%, suppression is typically effective.

Besides dilution of oxygen concentration, another means for extending the chemical reaction time in a combustion zone is to reduce the frequency of effective chain propagating steps in the combustion process. The chemical activity of Halon-1301 falls under this category, where thermal dissociation of  $\text{CF}_3\text{Br}$  leads to formation of combustion-radical trapping bromine radicals,  $\text{Br}\cdot$ . There is considerable evidence in the literature that powders and dusts also exhibit some amount of chemical reactivity and can be particularly effective in the extinction and suppression of fires. Furthermore, particle size was shown to be a significant factor in powder effectiveness, with the work of Ewing et al.(6), indicating that many powders exhibit a plateau of high reactivity for powders smaller than  $< 20 - 50 \mu\text{m}$

Solid propellant gas generator technology provides an ideal platform for the creation and distribution of reactive powders, droplets and dusts. Since solid propellants typically react in a controlled but rapid fashion at very high temperatures, condensed byproducts from their combustion reaction tend to be of small particle size. The composition and particle size distribution of these aerosols can be controlled by taking advantage of propellant composition and reaction rate. These factors can be controlled both chemically and through proper design of the generator hardware. OAC has examined this capability of chemically reactive fire suppression agents via solid propellant processes.

OAC has demonstrated the effectiveness of SPGG fire suppression technology in aircraft engine nacelles (F-18 E/F), drybays (F-18 E/F, V-22)(7) and ground vehicle engine compartments. This presentation will review and discuss the concepts of solid propellants for fire suppression applications, as well as our findings regarding their distribution and effectiveness.

This work has been sponsored by Olin Corporation, Olin Aerospace Company, the U.S. Navy (Mr. James Homan), U.S. Air Force (Mr. Mike Bennett), and the U.S. Army/TACOM (Mr. Steve McCormick).

### **References**

1. J. C. Yang, W. L. Grosshandler, Eds., *Solid Propellant Gas Generators: Proceedings of the 1995 Workshop* (NIST, Gaithersburg, MD, 1995).
2. H. E. Filter, D. L. Stevens, U.S. Patent No. 3,972,820, 1976.
3. R. Reed, M. L. Chan, K. L. Moore, U.S. Patent No. 4,601,344, 1986.
4. L. D. Galbraith, G. F. Holland, D. R. Poole, R. M. Mitchell, U.S. Patent No. 5,423,384, 1995.
5. D. Guesto-barnak, et al., Fire Test Results for Solid Propellant Inert Gas Generators in the Walter-Kidde Aerospace Dry Bay Simulator, Halon Options Technical Working Conference Albuquerque, NM, 1996), pp. 75-87.
6. C. T. Ewing, F. R. Faith, J. B. Romans, J. T. Hughes, *J. of Fire Prot. Engr.* 4, 35-52 (1992).
7. P. Proctor, "Aviation Week & Space Technology," March 6, 1995, p. 47.